APPENDIX L

HYDROGEOLOGIC AND TRANSPORT CALCULATIONS

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Hydraulic Conductivities

Table 6-6 lists site-wide testing results for estimating the hydraulic conductivity (K) of overburden materials, i.e., fill, estuarine silt, alluvium and glacial outwash. Estimates of K derived from cone penetrometer results appear to be biased low, by as much as an order of magnitude, and so have not been included in the analysis below. Estimates of K derived from soil sample grain size distributions appear to be consistent with those from slug tests and have been retained in this analysis.

The Shapiro-Wilk test was applied to each of these subsets to see if they could be treated as normally or lognormally distributed in estimating mean values. Filliben's test was used where the total number of samples exceeded 50. The results are tabulated below:

At a 95% level of confidence:

Set	Number	Raw -W	LogT - W	Critical W	Conclusions
Fill	17	0.888	0.875	0.892	Neither normal nor lognormal, but nearly either
Estuarine	6	0.718	0.969	0.788	Hypothesis of lognormality could not be rejected
Alluvium	36	0.776	0.908	0.935	Neither normal nor log-normal, but nearly log-normal
Outwash	16	0.828	0.845	0.887	Neither normal nor log-normal, but more nearly log-normal
Alluv+Out	52	0.854	0.956	0.979	Neither normal nor log-normal, but more nearly log-normal

At a 99% level of confidence:

Set	Number	Raw -W	LogT - W	Critical W	Conclusions
Fill	17	0.888	0.875	0.851	Hypotheses of normal or lognormal could not be rejected
Estuarine	6	0.718	0.969	0.713	Hypotheses of normal or lognormal could not be rejected
Alluvium	36	0.776	0.908	0.912	Neither, but nearly lognormally distributed
Outwash	16	0.828	0.845	0.844	Hypothesis of lognormal could not be rejected
Alluv+Out	52	0.854	0.956	0.966	Neither, but nearly lognormally distributed

Overall, when all data are plotted, the Ks more nearly approximate a lognormal distribution, skewed right.

Assuming a lognormal distribution for each of these leads to an estimate of the median (as the appropriate measure of central tendency) of the following:

Fill	38.6	ft/d
Estuarine	6.3	ft/d
Alluvium	18.5	ft/d
Outwash	16.3	ft/d
Alluv+Out	17.8	ft/d

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The hypothesis of equal medians for the Alluvium and Glacial Outwash data sets was tested with the Wilcoxon Rank Sum Test. This hypothesis could not be rejected at the 95% confidence level.

Horizontal Hydraulic Gradients

The horizontal hydraulic gradient at the site is relatively flat, varying from about zero near groundwater divides present on-site, to a maximum of about 0.0022 near PZ-8 and PZ-4.

i = dH/dL
where
  i is the hydraulic gradient
  dH is the head differential between points on a flow line, ft
  dL is the distance between the points on the flow line, ft

i = 0.49/225 = 0.0022

Estimate of Groundwater Discharge to the Housatonic

This is estimated by calculating flow through geologic cross section A-A' along the Dike as follows:

Estimate the hydraulic gradient local to this section
Estimate the average thickness for flow to occur
Estimate the thickness of the fill, silt and alluvium and outwash across this section
Use the available K data at this section and calculate a thickness weighted K
Use Darcy's Law to calculate a specific discharge and multiply it by the cross section area
Based on recent bedrock explorations (Feb-March 2004) assume a 5-foot thickness of relatively dense, impermeable till overlying bedrock. This effectively reduces the overall average thickness from 104 to 99 feet, and the thickness of the alluvium/outwash from 72 to 67 feet.

Width of section	1750	ft
Thickness of section	99	ft
Thickness of fill	10	ft
Thickness of silt	22	ft
Thickness of alluvium	67	ft
Porosity	0.35	

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K data available on this cross section:

Ks of fill	120.2	83.7	125.7	ft/d				
Ks of silt	1.3	8.3	ft/d					
Ks of alluvium	3.6	13	31.7	29.7	25.5	211	89.7	ft/d

(Combine the first two estimates for the alluvium as they represent the same vertical location)

Take as averages the geometric means:

K fill	108.1
K silt	3.3
K alluvium	38.2

Thickness weighted K = 37.5 ft/d

Hydraulic gradient:	dH	dL	i
near WC5S:	0.5	262	0.00191
near WC2-3S:	0.4	219	0.00183
near MW-3	0.5	438	0.00114
average =			0.00163

Note these represent shallow/intermediate gradients. Deeper gradients are less reliable due to fewer data points for contouring. The flow model suggests similar gradients in the deeper alluvium as in the shallow.

Estimated discharge:

Q = K*i*Width*thickness = 10563 ft^3/d

Note: preliminary results from the WES flow submodel2 has as inputs 8507 ft^3/d recharge and 2045 ft^3/d from upgradient sources, for a total of 10552 ft^3/d. While a small amount of this exits the model in the northwest corner, the match between these two estimates is reasonably good.

<u>Site Average Groundwater Velocity</u>

The groundwater velocity will vary across the site depending on local divides, recharge areas, gradients and hydraulic conductivities. An average flow velocity for the site as groundwater exits the site may be computed for section A-A' as v = Ki/n

v = 0.17 ft/d = 63.6 ft/year

L-2

SUMMARY OF CONTAMINANT TRANSPORT CALCULATIONS

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Groundwater Velocity

For an average velocity, take the estimated total discharge to the river and divide by the cross sectional area (Section A-A'), and then divide this flux rate by the porosity to get an average seepage rate through this section.

Q =	10563	ft^3/d
Thick =	99	ft
Width =	1750	ft
Porosity =	0.35	

Average velocity = 0.17 ft/d

Estimate of Longitudinal Dispersivity

The approximate distance (L) from Bldg 2 to the river/tidal flats is 1300 ft
Denote the lonitudinal dispersivity as alphax

By the USEPA default rule of thumb, alphax = 0.1L
Alphax = 130 ft

By recommendations of Gelhar, alphax = alphax@500 ft *(L/500)^0.5
And alphax at 500 ft = 65.1 ft
alphax = 105.0 ft

By the method of Xu and Eckstein, alphax = $3.28*0.82*[\log_{10}(L/3.28)]^{2.446}$
alphax = 27.8

The average of these values is 88 ft

Note that for Ks and velocities in this range, diffusion has a negligible contribution to the overall dispersivity.

Estimate Retarded VOC Contaminant Velocities

Estimate these for 1,1-DCE, TCE and PCE

Use a linear partitioning assumption for sorption, then the retardation coefficient R becomes

R = (1+ rhob*foc*Koc/n)

where

rhob is the soil bulk density	1.7	g/cc	(assumed)
foc is soil fraction organic carbon	0.0015		(assumed)
Koc is organic carbon partition coefficent (chemical specific)			
n is the aquifer effective porosity	0.35		(estimated)

Compound	Koc	Retardation	Contam vel	
1,1-DCE	65	1.47	0.118	ft/d
TCE	126	1.92	0.091	ft/d
PCE	364	3.65	0.048	ft/d

Plume Dilution Factors

Use equation for transport from Domenico and Schwartz (1990, p. 649, equation 17.22)
This equation can be simplified for steady state conditions along the plume center line
and no degradation (lamda = 0) to give

C/C_0 = erf[Y/(4*(alphay*x)^0.5)] * erf[Z/(2*(alphaz*x)^0.5)]

where

C is the concentration at some distance x from the downgradient edge of the source area
C_0= the initial concentration in the source area
alphay is the transverse dispersivity
alphaz is the vertical dispersivity
Y is the width of the source area
Z is the thickness of the mixing zone (thickness of the plume at the source)

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This may be familiar as the basis for USEPA's generic vertical and horizontal spread (VHS) model.
In the second erf term, the factor 2 appears as dispersion in only one vertical direction is allowed (e.g., downward spread only for a water table plume, or a lower confinig layer for a deep plume)

Gelhar recommends ratios for the alphay and alphaz as alphay/alphax = 8 and alphax/alphaz = 160.

alphay =	10.95	ft
alphaz =	0.55	ft

The following table gives estimated dilution factors for each of the three VOC hot-spots at various distances from the source and for each of the three principal groundwater contaminants (the estimated time to reach the distance is the retarded velocity)

Hotspot	Width (feet)	Thickness (feet)
1	150	41
2	75	20
3	120	32

VOC Hot-spot	Compound	Distance	Time, days	Time, yrs	C/C_0
1	1,1-DCE	100	846	2.3	0.891
		500	4230	11.6	0.485
		900	7613	20.9	0.329
		1300	10997	30.1	0.248
	TCE	100	1101	3.0	0.891
		500	5505	15.1	0.485
		900	9909	27.1	0.329
		1300	14314	39.2	0.248
	PCE	100	2096	5.7	0.891
		500	10482	28.7	0.485
		900	18868	51.7	0.329
		1300	27254	74.7	0.248
2	1,1-DCE	100	846	2.3	0.545
		500	4230	11.6	0.170
		900	7613	20.9	0.100
		1300	10997	30.1	0.071
	TCE	100	1101	3.0	0.545
		500	5505	15.1	0.170
		900	9909	27.1	0.100
		1300	14314	39.2	0.071
	PCE	100	2096	5.7	0.545
		500	10482	28.7	0.170
		900	18868	51.7	0.100
		1300	27254	74.7	0.071
3	1,1-DCE	100	846	2.3	0.798
		500	4230	11.6	0.359
		900	7613	20.9	0.229
		1300	10997	30.1	0.168
	TCE	100	1101	3.0	0.798
		500	5505	15.1	0.359
		900	9909	27.1	0.229
		1300	14314	39.2	0.168
	PCE	100	2096	5.7	0.798
		500	10482	28.7	0.359
		900	18868	51.7	0.229
		1300	27254	74.7	0.168

Note: travel times are based on the estimated average at section A-A'. Velocities may vary across the site depending on local conditions of gradient, hydraulic conductivity, and fraction organic carbon.